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High resolution measuring system for domestic hot water consumption. Development and field test.

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Abstract

Much effort has been put in tightening the building regulations. Though, the energy usage for domestic hot water stayed unchanged constituting a bigger share of the energy pie over the years. Due to the cost, timeframe, and workload associated with instrumentation and installation, the vast majority of the DHW measurements are limited to the household level. This paper introduces a high resolution measuring technique for DHW consumption and its application in a single family house. By applying this technique, we are able to measure the duration, flow and temperature of each water draw event in the house and thus create both the temporal and spatial DHW consumption profiles. The results indicated that the duration of draws varies significantly between tapping places, i.e. the draws in the shower and in the kitchen have an average duration of 300 sec. and 20 sec., respectively. The high resolution metering system was able to record the inefficient use of DHW, at periods when the water temperature was not meeting the users' requirements, e.g. the wasted energy at the shower depending on the usage pattern varies between 25% and 42%. The measured temperature range of DHW in the household is between 52°C (kitchen) and 21°C (sink in utility room).

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Keywords: Domestic hot water measurements; high resolution measuring system; household energy consumption; draw profiles; field test

1. Introduction

By accounting for roughly 40% of total energy consumption and 36% CO₂ emissions in the European Union [1]

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buildings have a prominent role in the transition to a low-carbon future. At the international level, DHW accounts for a significant share of total energy consumption in the residential sector, i.e. 18% in USA, Canada and 14% in European Union [2,3], which could be exploited to support the green transition, e.g. in France control of 14 million of electric boilers provided 8GW of flexibility available for use in the power system [4].

Much effort has been put in tightening the building regulations (BR). Thereby, significant reduction in the energy used for building operation, primary in space heating consumption, has been achieved. Though, the energy usage for domestic hot water (DHW) stayed unchanged constituting a bigger share of the energy pie over the years. As depicted in Fig.1 in the existing Danish buildings the DHW use represents 21% of total energy consumption, while in energy efficient buildings it can go up to 41%. In Netherlands, the DHW use in the existing buildings is responsible for 23% of the household gas consumption, and in new buildings this contribution reaches 50% of the energy consumption [5]. If the hot water consumption is broken down into more detailed statistics, such as water consumption per person [$\text{m}^3/\text{person per year}$], it can be noticed that in Denmark between 1987 and 2016 the consumption of hot water has increased by approximately 50% [6,7].

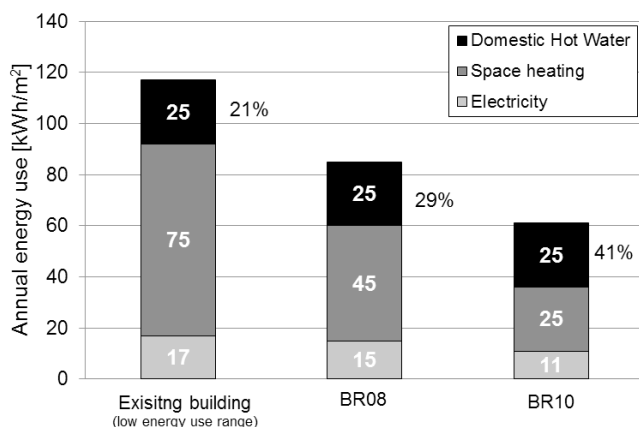


Fig. 1. Distribution of annual energy use for hot water, space heating and electricity in existing building and in new house building according to building regulations (BR) 2008 and 2010 [6].

Due to the cost, timeframe, and workload associated with instrumentation and installation, the vast majority of the DHW measurements are limited to the household level [8]. The existing measured data on water draw events is collected several decades ago and may no longer reflect current consumption pattern in residential buildings [2]. Finally, with the emergence of the smart meters, the DHW studies are based on the data delivered by the companies delivering and metering heat. However, these data are commonly on 1-hour resolution, which is too low considering that duration of water draw event varies between 0.6-10 minutes [2].

In order to fill this gap in knowledge of DHW consumption patterns, this paper introduces a high resolution measuring technique for DHW consumption and its application in a single family house (the test house). By applying this technique, we are able to measure the duration, flow and temperature of each water draw event in the house and thus create both the temporal and spatial DHW consumption profiles. Having these profiles allows selecting the energy efficiency measures that most significantly will contribute to reduction of energy use for DHW and hence contribute to the overall energy reduction of the building sector.

The rest of the paper is organized as follows. First part presents the measurement method, i.e. details on the instrumentation used and the physical placement of this instrumentation in the test house. Second part presents the measured data, which deliver new knowledge for further energy reduction.

2. Measurements

2.1. Measurement set-up

The measuring system will be used to record data to prolong periods of time in a large number of diverse tapping locations, where the space for installation of the setup and access to power plugs might be limited. Therefore, it needs to be a standalone system, which is easy to use, access and mount and able to carry out the measurements at a high resolution. It should also be a flexible solution, which can address the particularities of different DHW installations, e.g. age, configuration.

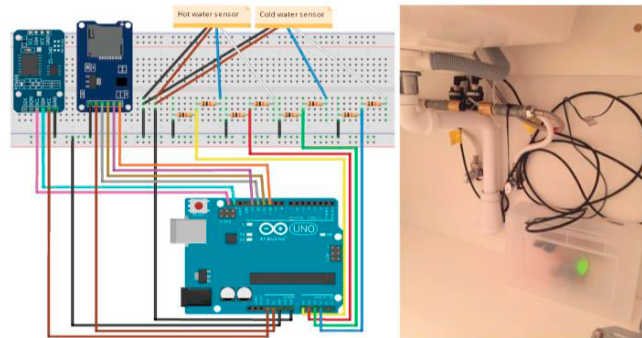


Fig. 2. Setup diagram (left) and setup in the field test (right)

Fig.2(left) shows the diagram of the created setup. It consists of:

- Two Swiss made Huba control 210 sensors that are vortex flow meters with a temperature sensing element – PT1000. The advantages of using a vortex flow meter include: a) measuring with high long term accuracy, b) a wide measuring range, unaffected by changes in pressure, temperature and viscosity of the fluid, c) very little maintenance over their lifetime due to lack of moving parts that wear out fast. Though the disadvantages are a) the required inlet/outlet sections at higher velocities, b) inaccurate readings for the flow rates at the low-range end.
- Arduino Uno R3 microcontroller for recording the data, which can be either a standalone device or a part of a computer setup.
- Micro SD card of 2GB capacity for data storage, which can store approx. 4 months of data. By using micro SD card the setup is able to function remotely and standalone.
- DS3231 RTC (Real-Time clock) module with separate power supply in order to be able to log time and duration of draws even if Arduino loses power supply and resets the integrated clock.
- A breadboard for assembling all components together
- Wall-wart power supply.

The Huba sensor measures both the flow rate and the temperature and gives an analogue voltage output in the range of 0 to 10V. However, the analogue pins on the Arduino board are limited to a maximum voltage input of 5V. Therefore, voltage dividers were introduced into the setup circuit before each of the sensor's output was connected to the Arduino analogue pins.

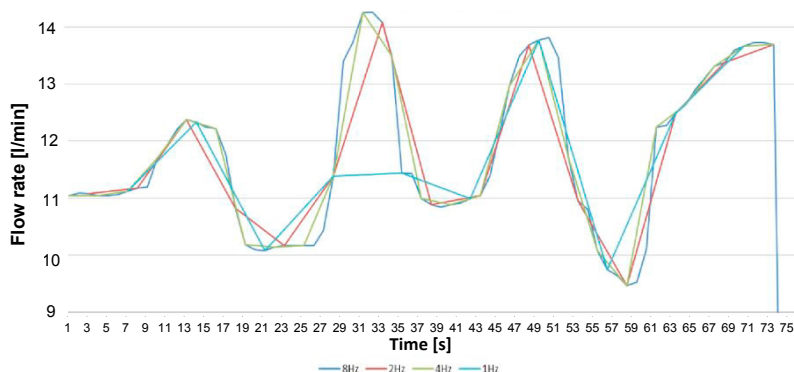


Fig.3. Results of frequency test of the setup.

When measuring non steady state fast varying quantities, a slow sampling rate might result in losing important peaks or valleys in the measurement profile. Yet, too much data can easily become troublesome to handle, therefore unnecessarily high sampling rate should also be avoided. In order to determine the appropriate sampling rate a frequency test is performed by mimicking the tapping of a sink, at sampling rates of 1Hz, 2Hz, 4Hz and 8Hz. As depicted in Fig.3 sampling data at frequency of 2Hz, which corresponds to data lagging of every 500 milliseconds, is the most sufficient for recording accurately the fluctuations of the flow rate.

2.2. Field test

In order to test the developed measurement setup, the instruments were placed in a single family house of 173m² that was built in 1970's. The household consists of 2 adults and 3 teenagers. Five setups with 9 sensors were installed. The placement is summarized in Table 1. Four setups are used to record the data at the sinks located in different rooms and one for the shower. It should be mentioned that due to the installation of the sensor on the mixing shower fixture and not the supply pipes, already mixed hot and cold water is measured. Fig.2(right) shows an example of how the sensors were mounted under a tapping place. The total measuring period was 2 weeks noon 10th of December until noon 24th of December.

Table 1. Overview of the set-up placement in the test house

Type of the room	Number of setups installed
Bathroom sink#1	1 with 2 sensors
Bathroom shower	1 with 1 sensor (mixing battery under shower)
Toilet sink #2	1 with 2 sensors
Kitchen	1 with 2 sensors
Utility room sink#3	1 with 2 sensors

3. Results

Fig. 4 shows the flow and temperature measurements for all tapping places. The water flow rate depends on the location of the sink and its purpose. In the kitchen when the sink is used for multi purposes, i.e. washing hands and dishes, drinking water, both the water flow and the DHW temperature are higher compared to other sinks in the house. The placement of the cold and hot water supply pipes is important. As indicated by the temperature results of cold water, in case of sink#1 it is much warmer than for the other sinks, since both supply pipes are located in common insulated cavity. The distribution of water low tares clearly indicates that in sink#2 the users use only hot draws, as in sinks #1 and #3 mix draws. The DHW temperature ranges between 52°C (kitchen) and 21°C (sink#3).

Due to size limit of this paper, the remaining results include only the detailed measurements from the shower and the kitchen sink. The rest of the results can be found in [9].

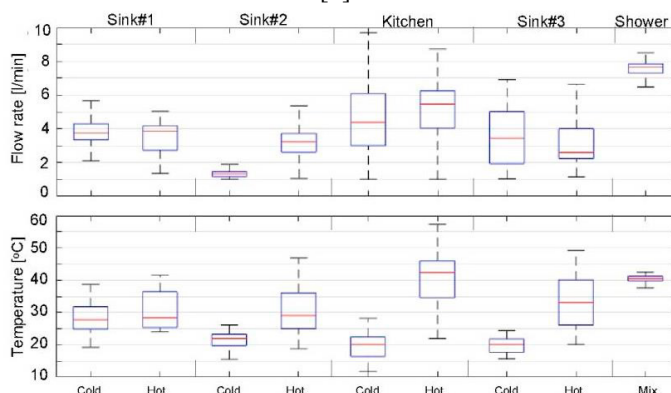


Fig. 4. Overview of water flow and temperature during measurement period.

3.1. Bathroom shower

The shower is mostly used in the early mornings and in the evenings during weekdays, with the peaks being at around 06:00 and 18:00. The weekend usage is more arbitrary, as it varies between 07:00 and 12:00. As expected, the duration of the draws in the shower is longer than in the other setups. As depicted in Fig.5 (left) most of the draws have duration of up to 300 seconds.

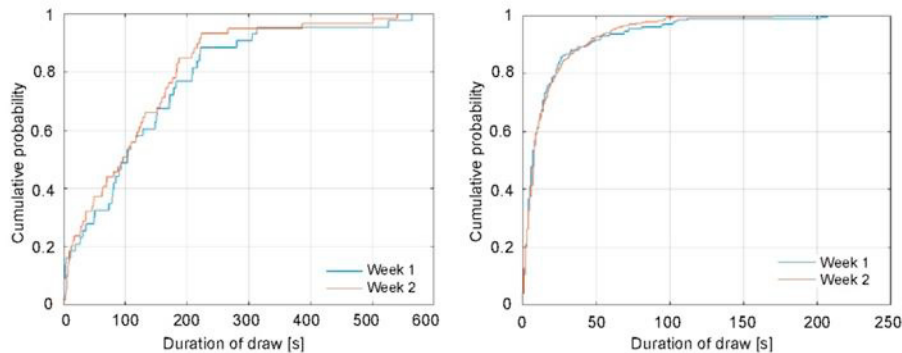


Fig. 5. Cumulative probability of duration of water draws in the shower (left) and in the kitchen sink (right).

By simultaneous high frequency measurements of the flow and the temperature we were able to analyse what happens during the individual draw of the water. Fig. 6(left) illustrates a sample of a morning usage of the shower, where one slow tapping with duration of 5 min was recorded. During the tapping, the flow increased from 7,5 l/min to 8 l/min, while the temperature increased from 24°C to 40°C after 74 second. The first 12 seconds were necessary for the system to displace the cooled-off water sitting in the pipes and the next 62 seconds for the circulated DHW to reach the desired temperature. The first 74 seconds can be considered as a waste of energy if the tapping is an ineffective, which is 25% from the total tapping period. For the on-off draws, see Fig.6(right), during the pause the temperature decreases by approx.3K and the recovery time is less than 30 seconds. This proves that once there is a circulation of DHW in the pipes, the waiting time for reaching the desired temperature is lower. The wasted energy due to ineffective tapping is 42%. When eliminating the waste energy time from the data, the temperature range of the hot water is narrow, only 6K with minimum of 37°C and maximum of 43°C.

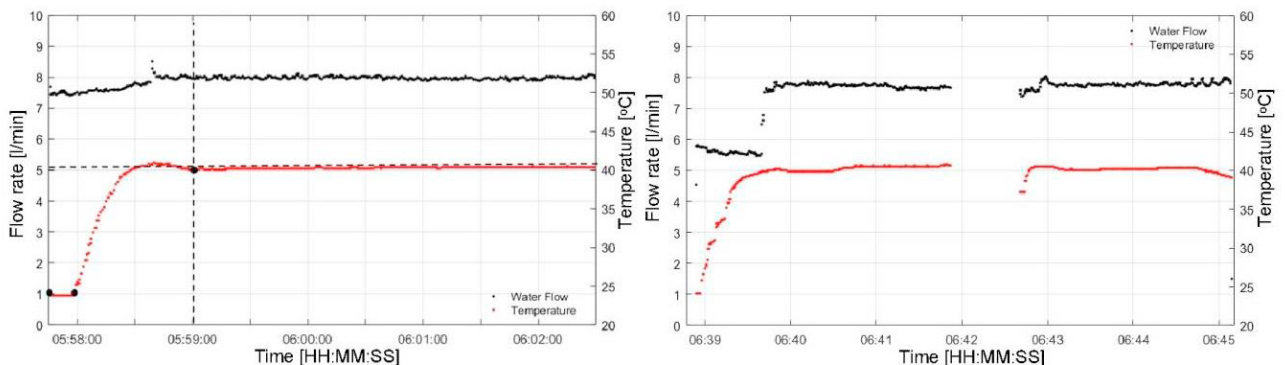


Fig.6. Sample of water usage in the morning on during uninterrupted shower (left) and on-off shower (right).

3.2. Kitchen sink

At the kitchen sink the DHW usage is mostly concentrated in the late afternoon and in the evening (cooking peak and dishwashing activities afterwards). Also this tapping place has the highest usage of DHW, see Fig4. It is a consequence of high temperatures needed for dishwashing. When looking at the number of draws, it is observed that in the kitchen the cold water draws are much more frequent than the hot water, i.e. 821 over 527 during the two weeks of measurements. It is a consequence of the using tap water as drinking water in Denmark. The draws' duration is in the range from 5 to 100 seconds, see Fig.5 (right). However 80% of the time, the tapping duration is below 30 seconds, which indicates that users use the tap for short activities, e.g. fill in the kettle, wash hands, rinse vegetables/fruits. This usage pattern may have a significant influence on the performance of the instantaneous heat exchanger, which produces DHW in the house, i.e. due to many short draws and numerous activations of heat exchanger, the “afterrun” which is the heat flow after the tapping is over, becomes a large waste of heat and thus the efficiency of heat exchanger is decreased. According to DS 439[10], the desired temperature for a kitchen sink is 45°C. According to measurements above 60% of time the temperature measured at the kitchen sink is in the range of 40°C to 45°C.

4. Conclusions

At the international level, DHW accounts for a significant share of total energy consumption in the residential sector. Yet for decades, the vast majority of the applied energy efficiency measures have focused on reducing the energy consumption for building operation, i.e. space heating and ventilation, and the domestic hot water has been overlooked. This paper aims to repair this neglect by presenting a high resolution metering system, which enables more precise measurements and thus delivers new knowledge of DHW consumption needed for development of effective energy efficiency measures.

The use of a high resolution metering system enables more precise measurements to be recorded. Their ability to record more detailed data and provide basis for a more in-depth analysis is confirmed, since the measurement process was successfully carried out. The high resolution metering system was able to record the inefficient use of DHW, at periods when the water temperature was not meeting the users' requirements. This is illustrated by the heat losses measured for each setup. The temperature range measured in the household is generally lower than the levels stated in the standard for design of water systems – DS 439 [10]. This can be attributed to the fact that the inhabitants mainly use DHW in the kitchen sink and shower, whereas in the other sinks, primarily cold water is used.

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